ER-LSP Setup for Multi-Service in Lambda Labeling Network

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Abstract— **Generalized Multiprotocol Label Switching (GMPLS) is being applied to optical networks as a means of moving control functionality from the management plane to the control plane, and automating lightpath provisioning and maintenance. GMPLS enables IP networks with Quality of Service (QoS) to be traffic engineered efficiently. However, computation of explicitly-defined paths optimizing network performance is a difficult task. Previous versions of these optimization routines have not taken path delay, including queueing delay at layer 3, into account. In this paper we present a technique for traffic engineering in optical networks that support QoS considering the traffic flows with delay QoS constraint across lambda labeling networks. The proposed mechanism would facilitate lambda label path setup with specific dealy QoS requirements.**

I. Introduction

The rapid growth in data traffic currently being experienced is fueled by the Internet, posing new challenges for transport network providers. To meet the bandwidth demand of the Internet, it is natural to use optical technologies with Wavelength Division Multiplexing (WDM) to offer the capability of building very large wide area networks with throughput of the order of terabits per second.

Recently, with the advent of new traffic engineering protocols like GMPLS, there has been considerable activity in several standards groups to integrate GMPLS and WDM networking technologies into a unified structure for the Internet. GMPLS will allow many carriers to deploy optical Internets where wavelengths (lambdas) are treated as very low level point to point links for the transmission of packets between high performance routers. In this lambda labeling network, optical switches translate label assignments into corresponding wavelength assignments and setup lightpaths using local control interfaces to switch devices. Subsequent to lambda LSP setup, no explicit label lookup/processing operations are performed by Optical Labeling Switched Routers (O-LSRs).

One of the benefits of GMPLS is that it supports Traffic Engineering (TE) by allowing the node at the network ingress to specify the route that a LSP will take by using explicit routing (ER). An explicit route is specified by the ingress as a sequence of hops that must be used to reach the egress, which is different from the hop-by-hop routing that is usually associated with packet-switch capable (PSC) networks. ER features can also be used to facilitate QoS support for multiple class of services in lambda labeling networks (e.g. DiffServ). There have been several efforts directed towards using QoS information to make routing decisions, but their focus is different from ours. A method for supporting QoS using the IETF's Open Shortest Path First (OSPF) routing protocol can be found in [2]. This approach advertises available bandwidth and delay metrics in OSPF Link State Advertisements (LSAs), but does not use the delay metric in computing paths. A great deal of attention has been given to distributed routing algorithms for QoS support, versus the centralized routing scheme that we are proposing. For example, a number of approaches have been developed to advertise QoS information in IP networks, including one that uses node aggregation in a fashion similar to that used in the Private Network-Network Interface (PNNI) routing protocol. Some centralized routing schemes have been proposed, notably that in [12], which seek to find the transiting path whose delay is less than a prescribed limit and whose bandwidth is greater than a specified lower bound. That approach uses Dijkstra's algorithm to find a suitable path but does not specifically account for delays at layer 3 or for relative throughput, as our algorithm does.

Routing that accounts for QoS constraints can be extended to optical networks, as discussed in [4]. Because the usual offline routing mechanisms are concerned only with minimizing the number of hops that a given path takes to cross the network, certain links between can become congested even though other (possibly underutilized) links are available on alternate paths. This results in an unnecessary higher delay for some traffic while resources elsewhere in the network go unused.

In this paper, we propose a mechanism to provide better delay QoS in the optical network by efficiently utilizing the available wavelengths. We do this by using a linear programming approach that seeks to minimize the total path delay, including delay introduced by packet processing at

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layers above optical. While other researchers, specifically [5], have introduced linear programs that account for the bottleneck effect at layer 3, their approach seeks to maximize total network throughput, while ours is focused on meeting QoS requirements.

The optimization routine that we are proposing will take path delay, including queueing delay at layer 3, into account. In an optical network using lambda labeling, processing at layer 3 would constitute a significant bottleneck whose impact we wish to minimize. In transparent optical networks where it is possible to create lightpath connections between every pair of edge routers, this is not an issue. But in large networks with thousands of devices at the edge, creating a virtual topology that is a full mesh is impractical. Thus, we can expect that intermediate nodes with layer 3 functionality will exist in a lambda labeling network (most likely at the edges of optical subnetworks in the core). Thus it would be useful to account for the impact of layer 3 processing when the ingress computes the explicit route. The layer 3 processing overhead at intermediate nodes is accounted for in the proposed path set-up algorithm.

II. Basic Elements in System Model

The optical core network can be homogeneous or it can consist of multiple optical subnetworks, each of which is administered by a single entity such as a large carrier. The subnetworks are, in general, composed of a mixture of transparent optical switches (known as photonic cross-connects (PXCs)) that do not perform any optical/electrical/optical (O/E/O) conversions and opaque optical switches (known as Optical Cross-Connects (OXCs)) that carry out some type of O/E/O operations. Some OXCs may also incorporate higher-layer processing functions, such as support for the IP and GMPLS protocol suites, or other technologies such as ATM, Frame Relay, Ethernet, and SDH/SONET. We refer to any OXC that processes packets using label switching as an Optical Label-Switching Router (O-LSR). O-LSRs can be viewed as a combination of a router and an OXC. The router component is responsible for all the layer 3 functions such as addressing, routing, and global topology discovery. It is also responsible for optimizing network performance, which can be carried out via TE with QoS support, management of optical resources (i.e. wavelength assignment in coordination with the optical channel sublayer), and restoration. Each OXC is capable of switching a data stream from a given input port to a given output port by appropriately configuring an internal crossconnect table. A lightpath is established by setting up suitable crossconnects in the ingress, egress and a set of intermediate OXCs such as that a continuous physical path exists across the optical network.

In this paper, a mechanism is proposed to support multiservice transport in lambda labeling capable networks. The virtual topology (virtual network) is made by routing the lightpaths over the physical topology. Then, the wavelengths are assigned dynamically to the lightpaths for multiple service classes. When a new flow is to be routed through the network, an ingress O-LSR determines the virtual path it will be routed through, in terms of the QoS requirements of the flow, such as the maximum acceptable delay. We consider prioritiy as another important element for TE. Although, in this paper, two levels of priority are taken into account where priority access to wavelength is given to the QoS service class over Best Effort (BE) traffic, the proposed mechanism extends to multiple priority levels. In an lambda labeling capable IP network of considerable size, two different service classes are assumed to be supported: Delay Sensitive (DS), and BE service classes [6].

TE has been usually associated with offline routing, where it is assumed that all tunnels or LSPs that are to be routed and their associated resources such as wavelengths are known at the time that routing is done. However, it is likely that the new requests need to be set up after the previous requests have been processed or that the QoS requirements of existing requests may change over time in a real network. So, it will be better to route using an online TE algorithm for the future requests in order to accommodate QoS requirements of these new requests. The proposed TE mechanism can be applied to online as well as offline routing.

The RSVP-TE and CR-LDP signaling protocols [7], [8] are both used in GMPLS to support lightpath services. When ER is applied to lambda labeling, the LSPs can be set up by specifying the addresses of the GMPLS nodes along the route in the Explicit Route Object (ERO), which is carried by both signaling protocols.

III. ER-LSP Set-up Algorithm

We consider a network consisting of N OXCs with a fixed number of ports. A subset of these nodes are assumed to be edge O-LSRs between which lightpaths can be set up. We assume the virtual topology is either known administratively or that a link state routing protocol is operational and that its link-state database is accessible. The algorithm routes the lightpaths over the topology, and assigns wavelengths optimally to the various lightpaths. This assignment problem has been shown to be NP-hard in [9].

The physical network is represented by a directed graph $G(\mathcal{N}, \mathcal{L})$ where $\mathcal{N}$ is the set of nodes and $\mathcal{L}$ is the set of links (*i.e.* fibers) connecting the nodes. Let $\mathcal{K}$ be the set of traffic demands belonging to the DS service class between a pair of edge O-LSRs. Each request $k \in \mathcal{K}$ is defined by the ordered triple (I_k, E_k, ε_k), where I_k is the ingress

OXC, E_k is the egress OXC, and ε_k is the maximum edge-to-edge delay that is allowed for request k. For traffic flow, we define λ_{ij}^{IE} to be the traffic from ingress I to egress E that flows over an intermediate virtual link between node i and node j. Also, $\lambda^{I_k E_k}$ denotes the average flow associated with the k^{th} traffic demand belonging to the DS service class requesting ER-LSP set-up.

To formally model the logical topology that is overlaid on the physical network, we introduce a set of logical connectivity variables

$$v_{ij} = \begin{cases} 1 & \text{if the virtual topology has a direct fiber link} \\ & \text{from node } i \text{ to node } j, \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where $i, j = 1, 2, \ldots, N, i \neq j$.

We also introduce a set of variables that define the ER-LSP whose path is to be determined by the routing algorithm:

$$e_{ij} = \begin{cases} 1 & \text{if the ER has a lightpath} \\ & \text{from node } i \text{ to node } j, \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where $i, j = 1, 2, \ldots, N$ and $i \neq j$. As in [10], e_{ij} indicates whether the ER-LSP is routed over the virtual link from i to j.

The constraint conditions are defined as follows.

$$\sum_j v_{ij} \leq T_i, \qquad \sum_i v_{ij} \leq R_j \qquad \text{for all } i, j. \tag{3}$$

where T_n and R_n are the number of transmitters and receivers, respectively, at node n $(n = 1, \ldots, N)$.

The total traffic from node i to node j, λ_{ij}, is

$$\lambda_{ij} = (v_{ij} \sum_{I,E} \lambda_{ij}^{IE}) + e_{ij}\lambda^{I_k E_k} \qquad \text{for all } i, j. \tag{4}$$

$$\sum_j e_i j - \sum_j e_j i = \begin{cases} 1, & i = I_k \\ -1, & i = E_k \\ 0, & \text{else} \end{cases} \tag{5}$$

$$\lambda_{ij} \leq W_{ij} C, \tag{6}$$

where C is the capacity of each wavelength on a fiber and W_{ij} denotes the number of wavelengths per link in the virtual topology between the nodes i and j for all i and j.

$$\lambda_{ij}^{I_k E_k} = e_{ij}\lambda^{I_k E_k}. \tag{7}$$

$$e_{ij} \leq v_{ij}. \tag{8}$$

Constraint 3 ensures that the number of lightpaths originating from and terminating at a node is not more than the node's out-degree and in-degree, respectively. Constraints 4 and 5 are related to the traffic flow on virtual topology for all i and j. Note that because we are setting up an ER-LSP, the traffic flow $\lambda^{I_k E_k}$ will not bifurcate at any point in the network, and the traffic flowing into an OXC should be equal to that flowing out of the OXC for any OXC other than the ingress and egress OXCs. Constraint 6 assures that traffic flowing through a link can not exceed the total link capacity. It is specified in constraint 7 that if the link between i and j is not part of the ER-LSP, no traffic associated with the new flow can exist on that link. Finally, constraint 8 prevents the ER-LSP from being set up between two nodes if there is no virtual link connecting them.

For the constraint 6, the layer 3 port throughput can be considered. When the traffic flowing through a link is going forward an intermediate O-LSR, the traffic demand should not be larger than the sum of the maximum throughput supported by IP router port:

$$\lambda_{ij} \leq W_{ij} C\{1 + (\alpha - 1)Q_j\}, \tag{9}$$

where $\alpha \leq 1$ denotes the maximum layer 3 port throughput, expressed as a fraction of the optical layer throughput, and Q_j indicates the layer 3 routing capability of the node as follows:

$$Q_j = \begin{cases} 0, & \text{Node } j \text{ has no layer 3 processing} \\ 1, & \text{Node } j \text{ has layer 3 processing} \end{cases} \tag{10}$$

A packet traversing the explicit route experiences an end-to-end delay of $\sum_{i,j} e_{ij}\lambda_{ij}^{I_k E_k} D_{ij} + d_{node}$, where the matrix $\mathbf{D} = \{D_{ij}\}$ contains the propagation delays from node i to node j, $i \neq j$ and d_{node} denotes the total waiting time at all nodes on the ER-LSP. At the optical layer, the packet processing delay at any O-LSR is small relative to the delay associated with processing at the higher layers. Thus d_{node} is defined to be the waiting and processing time at O-LSRs, since these nodes are the likely bottleneck points on any ER-LSP.

Since there can be an arbitrary number of intermediate O-LSRs on the LSP, we define λ_m^{IE} to be the aggregate input rate to the m^{th} $(m = 1, 2, \ldots, M)$ O-LSR. By employing the independence assumption on interarrivals as shown in Fig. 1, we can model the delay experienced at layer 3 using an M/M/1 queueing model. The variable μ_m^{IE} denotes the service rate in each intermediate node and the variable $\rho_m^{IE} = \lambda_m^{IE}/\mu_m^{IE}$ is the utilization.

For the k^{th} traffic flow belonging to DS class, the objective function for delay can be written as

$$f(e_{ij}) = (\sum_{i,j} e_{ij}\lambda^{I_k E_k} D_{ij}) + \tau, \tag{11}$$

where $\tau = \sum_{m=1}^{M} \frac{\rho_m^{IE}}{(1-\rho_m^{IE})\lambda_m^{IE}}$ is the average layer 3 processing delay seen by the traffic. We can rewrite this using

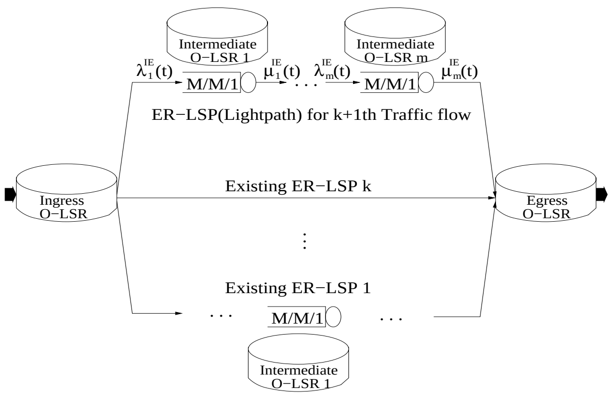

Fig. 1. Delay when intermediate nodes exists

the local connectivity and processing rate variables as

$$\tau = \sum_{i,j} \frac{e_{ij} Q_j}{\mu_j - (\sum_\ell \lambda_{\ell j} + \lambda^{I_k E_k})}. \tag{12}$$

In Eq. 11, the second term τ will be zero if there is no layer 3 processing at any point on the ER-LSP. The objective function, Eq. 11, should be minimized in order to support the delay QoS requirement of the k^{th} flow from the DS class. If the miniminum value of Eq.11 does not satisfy the delay QoS requirement, the values computed from the minimization would not be applied to the variable e_{ij}.

In addition to the constraints in (3 - 8), we define an additional two constraints which are related to QoS and layer 3 processing rate. One constraint for QoS can be defined as

$$0 \le f(e_{ij}) \le \varepsilon_k. \tag{13}$$

The other constraint for layer 3 processing rate can be expressed as

$$\mu_j \ge v_{ij} \sum_i \lambda_{ij}^{IE} + e_{ij} Q_j \lambda^{I_k E_k} \qquad \text{for all } I, E. \tag{14}$$

The multicommodity network flow problem with integer constraints is generally known to be NP-hard [11]. The k disjoint route problem which is NP-hard in [11] can be dealt with the same as that the k distinct egress node pairs find k mutually link-disjoint routes.

Whenever a new traffic flow belonging to DS service class requests explicit route, the virtual lightpath will be configured and the network state will be updated. If it is not possible to support the ER-LSP with the desired QoS, the request can be blocked or renegotiated and attempted again. Alternatively, the network controller can preempt the minimum number of lower priority flows that will allow the ER-LSP to be set up. The procedure for the k^{th} request, which does not account for preemption, proceeds as follows:

Step 0: Obtain the parameters associated with the k^{th} setup request
Step 1: *if* a transmitter or a receiver is not available at I_k or E_k
  then go to Step 3;
Step 2: *if* there is any ER-LSP to minimize Eq. 11
  then go to Step 4;
  else if the request is negotiable
    then relax ε_k and go to Step 2;
    else go to Step 3;
Step 3: Block this ER-LSP request and go to Step 5;
Step 4: Provision resources for the ER-LSP and update network state;
Step 5: End;

To satisfy the requirements of diverse routing, rerouting and restoration as well as traffic engineering, explicit routing is necessary for constructing lightpaths. The route on which a new lightpath is to be established is specified by an object contained in the lightpath setup message. This route is typically be chosen by the ingress O-LSR, but it could be determined by a higher level network management system. The route may be specified either as a series of routers/OXCs, or in terms of the specific links used. Therefore, the above mechanism performs the calculation of primary and restoration lightpath routes on-line as the individual requests arrive. These lightpaths could be computed all at once by doing an offline calculation that accounts for all the pending requests.

Because the network loading varies over time, the consideration of the optimal route selection could require the reconfiguration of established lightpath routes, as described in [2]. Although frequent lightpath reroutings may not be acceptable, a limited number of lightpath reroutings could improve the network state, supporting the requested QoS of the future traffic while maintaining the QoS of the traffic that the network is already supporting. In the initial configuration stage where there is no configured virtual topology, the appropriate virtual lightpath could be found by repeating the above procedure. This procedure is applied to the traffic with the highest delay limit among all initial traffic demands of DS service class at all egress O-LSRs being done so to the traffic with the next delay limit in turn. Like setting up ER-LSP, the virtual topology would be configured for the traffic demand of DS service class at each egress OXC by minimizing the objective function of delay. By finding the values of all the elements of the set $\{\lambda_{ij}^{IE}\}$, we can obtain a full set of routing assignments for all the traffic in the optical network.

IV. Performance Results from Simulation

We analyzed the performance of the proposed algorithm and compared it to the well-known Shortest Path

First (SPF) algorithm using a set of simulations, which we discuss in this section. First, we describe a simulation setup used to validate our algorithm in providing service requested by DS class. We then compare the performance of the two routing algorithms. As a simulation tool, we used the simulator MERLiN [13] which was developed for WDM network simulation, for the analysis with our proposed algorithm described earlier. The simulation tests were carried out on a model of the network shown in Fig. 2, with wavelength number $W_{ij} = 4$ (for all i, j), *i.e.* a maximum of 4 wavelengths are available for use in each link. For this topology model, two cases were tested. While one case is that the values of the Q_j are assumed to be 1 for all the edge nodes, the other case the values are 1 for j=5,8,9,12 and 14. The propagation delay D_{ij} is assumed to be 0.05 for all i, j, and the maximum tolerable delay limit of for every request from DS traffic is 0.5. As for traffic generation, we assume that every traffic flow requesting ER-LSP is generated according to a Poisson point process with an arrival rate of $\lambda_{ij}^{I_k E_k}$. In the simulations we use arrival rates of 200 and 1000. We assume that the time between lightpath set up and teardown is exponentially distributed with a mean of 1. We generated the lightpath setup requests and the traffic flows uniformly at all edge nodes. When a ER-LSP setup request arrives at an ingress node, the destination is chosen randomly among all the edge nodes except the ingress with the setup request. 10% of total traffic flows belongs to the DS service class.

Fig. 3 and 4 show the blocking performance of DS traffic, for two cases where $1/\lambda = 0.001$ and $1/\lambda = 0.005$, respectively. Fig. 5 and 6 show the result from the other set of simulations where the location of the O-LSRs is changed, i.e. the layer 3 processing is at nodes 5, 8, 9, 12 and 14 only. As can be seen from the graphs, our proposed algortihm performed better with respect to the blocking rate, which means that the proposed algorithm utilizes network resources more efficiently.

Without performance degradation in blocking rate, the delay performance could be improved by considering layer

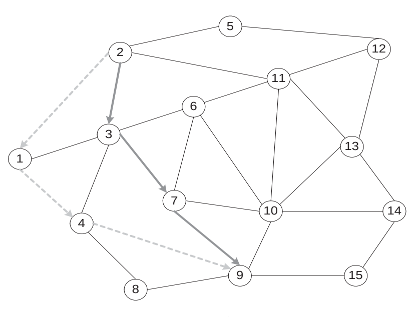

Fig. 2. Path setup

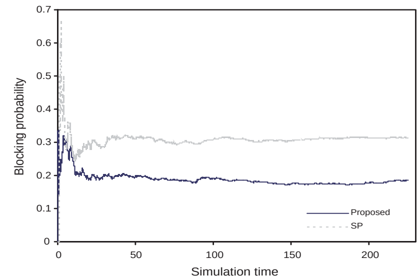

Fig. 3. Blocking probability ($1/\lambda = 0.001$)

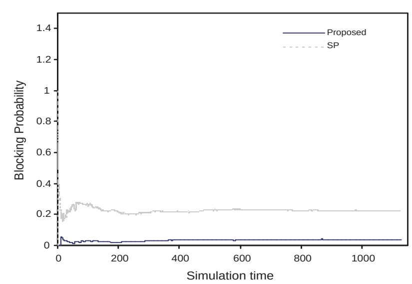

Fig. 4. Blocking probability ($1/\lambda = 0.005$)

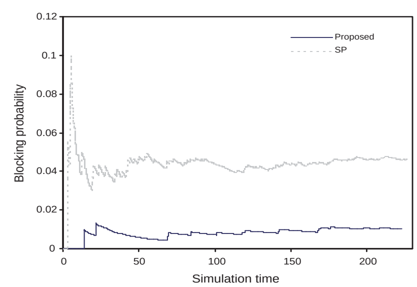

Fig. 5. Blocking probability ($1/\lambda = 0.001$)

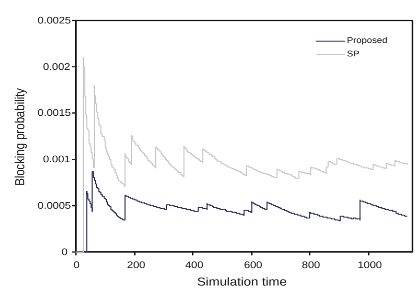

Fig. 6. Blocking probability ($1/\lambda = 0.005$)

TABLE I
DELAY PERFORMANCE

Case 1

$1/\lambda$	Proposed algorithm	SP algorithm
0.01	0.292	0.477
0.05	0.266	0.424

Case 2

$1/\lambda$	Proposed algorithm	SP algorithm
0.01	0.228	0.417
0.05	0.215	0.371

3 processing delay to set up a LSP. As can be seen in Fig. 2, the two algorithms chose different paths between souce node 2 and destination node 9. In other words, while the proposed algorithm selected the route (2→3→7→9), the SP algorithm chose the route (2→1→4→9). The average delay associated with both algorithms is presented in Table I measured during the overall simulation time for the two cases where one case performs layer 3 processing at all the edge nodes and the other case does so at only the 5 nodes listed above.

V. Conclusion

In this paper, we proposed an optimization algorithm to support the requested delay QoS of LSP requests in an optical network that uses lambda labeling to switch lightpaths. This algorithm uses the current state of the network to determine the delay associated with each possible path, and then chooses the path with the minimum total delay. A novel feature of this approach is that it accounts for the delay encountered by packets that require layer 3 processing at subnetwork edge nodes. Using a model of a meshed optical backbone network, we used the MERLiN tool to demonstrate that traffic assigned to LSPs with our algorithm experiences less delay and lower blocking probability than traffic that is assigned using a standard algorithm such as Shortest Path First.

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